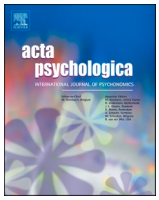
Acta Psychologica 215 (2021) 103288

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy



The processing of prices across numerical formats

Fernando Ojedo [a,b], Pedro Macizo [a,b,*]

[a] University of Granada, Spain
[b] Mind, Brain and Behaviour Research Center (CIMCYC), Spain

ARTICLE INFO

Keywords:
Price processing
Componential processing
Compatibility effect

ABSTRACT

We evaluated whether the format in which prices are presented determines the processing of their magnitude. A price comparison task was used in which two-digit prices with Arabic digits, written number words and auditory number words were presented in the euro currency. Prices were number-monetary category (NMC) compatible (49 euros - 36 cents) when the number and monetary category of one price were larger than those of the other (49 > 36, euros > cents); or NMC incompatible (49 cents - 36 euros) when the number of one price was larger but the monetary category smaller than those of the other (49 > 36, cents < euros). In addition, there were unit-decade (UD) compatible prices when the decade and unit of one price were larger than those of the other (49 euros - 36 cents, 4 > 3, 9 > 6); and UD incompatible prices when the decade of one price was larger but the unit smaller than those of the other (46 euros - 39 cents, 4 > 3, 6 < 9). The results showed NMC compatibility effects in all numerical formats. However, the UD compatibility effect was not found in any numerical format. The results are discussed within the hybrid model of multisymbolic magnitude processing.

1. Introduction

Handling money (coins, banknotes, price processing) is an everyday activity in our daily lives that involves numerical processing. Previous studies have investigated numerical processing in the context of price cognition and monetary cognition (Dehaene & Marques, 2002; Goldman et al., 2012; Macizo & Herrera, 2013; Macizo & Morales, 2015; Ruiz et al., 2017; Thomas & Morwitz, 2005), however, there is no a priori reason to believe that the cognitive mechanisms associated to the processing of prices are different from those responsible for the processing of other kinds of magnitude representation. In fact, price processing from a cognitive perspective could easily be integrated within a general framework of multi-symbolic magnitude processing (Huber et al., 2016). In this framework, it is proposed that all symbols representing a magnitude (e.g., numbers, units of measurement, etc.) are processed separately (Nuerk & Willmes, 2005). With respect to natural numbers (e.g., 38), people would independently process the ten (3) and the unit (8) to reach the magnitude of two-digit numbers. In the case of negative numbers (e.g., −7), people would process both the negative sign (−) and the digit (7) separately, etc.

Empirical evidence in favor of this componential analysis has been obtained in several studies that evaluate the possible conflict derived from the independent processing of multi-symbol magnitudes (Huber, Bahnmueller, et al., 2015; Huber, Cornelsen, et al., 2015; Macizo, 2017; Macizo et al., 2010; Macizo et al., 2011; Macizo & Herrera, 2008, 2010, 2011a, 2011b; Macizo & Herrera, 2013; Moeller et al., 2013; Nuerk et al., 2001). These studies have used the magnitude comparison task in which pairs of magnitudes are presented (e.g., pairs of numbers, pairs of units of length) and people have to select the one with the larger magnitude. In order to evaluate the possible conflict caused by the independent comparison of each symbol composing a magnitude, the compatibility between the results of these comparisons is considered. Thus, compatible trials are established in which the two symbols of one magnitude are larger than the symbols of the other magnitude (67–52, 6 > 5 and 7 > 2 in the case of a two-digit number; 5 cm - 4 mm, 5 > 4 and cm > mm in the case of units of measurement); and incompatible trials in which one magnitude contains a larger symbol and another smaller symbol compared to these symbols in the other magnitude (62–47, 6 > 4 but 2 < 7; 5 mm - 4 cm, 5 > 4 but mm < cm). The results of different studies have shown compatibility effects with poorer performance (slower and less accurate magnitude comparisons) in the incompatible condition relative to the compatible condition. This compatibility effect (e.g., for the case of two-digit numbers, the unit-decade compatibility effect, UD compatibility for short) suggests that people process the

* Corresponding author at: Departamento de Psicología Experimental, Facultad de Psicología, Universidad de Granada, Campus de Cartuja, s/n. 18071, Granada, Spain.
E-mail address: pmacizo@ugr.es (P. Macizo).

https://doi.org/10.1016/j.actpsy.2021.103288
Received 17 June 2020; Received in revised form 5 January 2021; Accepted 19 February 2021
Available online 6 March 2021

constituents of multi-symbol magnitudes separately. In addition, the interference produced by the processing of incompatible vs. compatible magnitudes is easily interpreted within a theoretical perspective of conflict resolution in numerical cognition (Macizo, 2017). In particular, the processing of the units in incompatible trials would interfere with the processing of the decades so that participants would have to inhibit the irrelevant information (the magnitude of the units) in order to correctly solve the comparison task.

However, the existence of componential processing does not entail that people can process at the same time the holistic magnitude in numerical comparison tasks (Moeller et al., 2011). Thus, from a hybrid perspective (Nuerk & Willmes, 2005), it would be argued that both the holistic and compositional processing of numerical magnitudes is possible (see Nuerk et al., 2011, for a review). In fact, recent studies have shown individual differences in the tendency towards holistic or compositional processing depending on factors such as the preference of people for global or analytical processing of hierarchical stimuli (e.g., Pletzer et al., 2019; Pletzer et al., 2020).

With regard to the processing of prices, the first studies suggested that prices composed of a number and a monetary category were not processed in a componential manner (Cao et al., 2012; Cao et al., 2015). Specifically, different studies conducted by Cao and colleagues revealed that the comparison of price pairs (2 yuan - 5 jiao) in the Chinese currency (1 yuan = 10 jiao) was performed holistically. From the holistic view, it would be defended that multi-symbol magnitudes would be analyzed as a whole and that the constituent elements would not affect the processing of prices independently. Cao and colleagues observed a distance effect between prices (worse performance with close vs. far distance price pairs) which suggested that the holistic magnitude of prices was processed. The authors did not found an independent influence of either the number or the monetary category which implied that the prices were not processed componentially. However, subsequent research conducted by Ojedo and Macizo (Macizo & Ojedo, 2018; Ojedo & Macizo, 2020) revealed that the pattern of results obtained by Cao et al. could be interpreted in terms of the compatibility between the symbols representing the digits and the monetary category of the prices.

In particular, Macizo and Ojedo (2018) evaluated the possible Number-Monetary Category (NMC) compatibility effect with a price comparison task in the Euro currency (Euro prices are composed of a number and a monetary category; 1 euro = 100 cents). The authors selected one-digit price pairs that produced compatible or incompatible comparisons when the number and the monetary category were independently considered. In compatible comparisons, the digit and the monetary category of one price were larger than those of the other price (e.g., 7 euro - 5 cent, 7 > 5 and euro > cent) while in incompatible comparisons, the digit of one price was larger but the monetary category was smaller than those of the other price (e.g., 5 cent - 7 euro, 7 > 5 but cent < euro). The results revealed a NMC compatibility effect with behavioral and electrophysiological measures (Macizo & Ojedo, 2018; Ojedo & Macizo, 2020, respectively). The results obtained with behavioral measures revealed that participants were slower and less accurate on incompatible price pairs relative to compatible trials. The electrophysiological results showed that the NMC compatibility modulated event-related components (ERPs) in the 350–450 ms time-window, with more negative amplitudes on incompatible trials relative to compatible trials. This electrophysiological NMC compatibility effect was interpreted as a N400-like component, an ERP component that has been related to conflict resolution in magnitude processing (e.g., Schwarz & Heinze, 1998; Szucs & Soltész, 2007). Thus, the results obtained by Ojedo and Macizo suggested that price processing is carried out in a componential manner, similar to the way in which people process other multi-symbol magnitudes (e.g., two-digit numbers).

However, although the pattern of results found in previous studies suggests that all multi-symbol magnitudes (e.g., prices, two-digit numbers) are processed in a componential manner, several studies show that the comparison of magnitudes is modulated by the format in which they are coded. For example, with two-digit numbers, the UD compatibility effect depends on whether the tens and the units are presented with Arabic digits or in verbal format (numbers written with words or numbers in auditory format). Specifically, with Arabic numerals, the UD compatibility effect is observed with worse performance in incompatible vs. compatible trials (Huber et al., 2013; Macizo & Herrera, 2008, Macizo, 2017; Macizo & Herrera, 2010, 2011a, 2011b; Macizo et al., 2011; Moeller et al., 2009; Moeller et al., 2013; Nuerk et al., 2001; Nuerk et al., 2005, for a review). However, when numbers are coded in verbal format (e.g., Spanish number words presented in written or auditory format) the results show no compatibility effect (Macizo & Herrera, 2008) or even a reverse compatibility effect with worse performance in compatible trials than in incompatible trials (Macizo & Herrera, 2010).[1]

The lack of compatibility effect or the observation of a reverse compatibility effect with number words has been confirmed in languages such as Spanish (Macizo & Herrera, 2008), Italian (Macizo et al., 2010), or English (Macizo et al., 2011; Nuerk et al., 2005), where two-digit numbers in verbal notation follow the decade-unit order (e.g., 37 = thirty-seven). In contrast, in languages where written number words follow the unit-decade order (e.g., German, 34 = vierunddreißig, literally, four and thirty), a regular compatibility effect is observed with verbal numbers (Macizo et al., 2010). This pattern of results indicates that people codify number words according to the internal structure of the language they speak. Thus, speakers of languages as Spanish, English and Italian, for example, might have learnt to pay more attention to decades because they are presented first when numbers are coded in verbal notation (e.g., auditory and written number words). On the contrary, speakers of languages such as German would pay more attention to the unit digit since it is processed first.

This pattern of processing based on a greater relevance of the first numerical symbol that is encoded in two-digit numbers (the ten, which is the leftmost symbol in written number words and the first digit heard in auditory numbers) would have direct implications for price processing. These implications are directly evaluated in the current study. Particularly, prices in euros follow the number - monetary category order (e.g., 37 euros, number = 37, monetary category = euro), which would imply an accentuated processing of the number when people read or heard a price presented with written or auditory number words.

However, the most relevant symbol for performing a price comparison task (e.g., 37 euros - 26 cents) would be the second constituent of a price, the monetary category, because its processing is enough to perform the task (i.e., the magnitude of euros is always greater than that of cents). It is important to note that the NMC compatibility effect is

[1] In most experiments, the overall distance between the two numbers in compatible and incompatible trials is typically matched. To compute the overall distance, the unit distance has to be added to the decade distance in compatible trials while the unit distance has to be subtracted from the decade distance in incompatible trials, and thus, the decade distance always has to be larger for incompatible vs. compatible trials. To illustrate, consider the compatible trial number pair 53–68 and the incompatible trial number pair 59–74. In the example, the overall distance of 15 in the compatible trial 53–68 results from 10 × the decade distance (6–5 = 1) plus the unit distance (8–3 = 5), (10 × 1) + (5) = 15. The overall distance of 15 in the incompatible trial 59–74 results from 10 x the decade distance (7–5 = 2) minus the unit distance (9–4 = 5), (10 × 2) – (5) = 15. Therefore, the decade distance has to be larger for incompatible vs. compatible trials to be able to subtract the unit distance. Moreover, because of this subtraction, the difference in decade distance between compatible and incompatible trials must be greater with large unit distances. Therefore, by virtue of these computational constraints, if participants only focus on the decade, they should be faster to make decisions on incompatible than compatible trials, an outcome that would be consistent with the distance effect (Moyer & Landauer, 1967). Please note that this explanatory footnote has been cited in other studies conducted in our research group evaluating the unit-decade compatibility effect with verbal numbers (e.g., Macizo et al., 2011).

evaluated with between monetary category price pairs (e.g., X euros - Y cents) where the processing of the number (X, Y) is irrelevant to determine the price of higher monetary value (i.e., X euros > Y cents and Y euros > X cents). Therefore, in the context of the NMC compatibility effect described above, an analysis where more attention is paid to the first constituent of the price (the number) would imply greater processing of the less relevant dimension of the price (the magnitude of the numbers) which would increase the NMC compatibility effect with prices in verbal format compared to prices presented with Arabic numbers.

In our study, participants performed a comparison task with prices composed of two-digit numbers. To evaluate the NMC compatibility effect across formats, price pairs could be NMC compatible when the number and monetary category of one price were higher than those of the other price (49 euros - 36 cents, 49 > 36 and euros > cents) or NMC incompatible when the number of one price was higher but the monetary category smaller than those of the other price (46 cents - 39 euros, 46 > 39 but cents < euros).

Furthermore, in our study, we used prices with two-digit numbers for two reasons. First, as far as we know, there are no previous studies evaluating the possible componential processing of prices with more than one digit. Second, this type of stimuli would allow us to examine the possible conflict associated to the processing of two-digit numbers in the context of price cognition. For this reason, in the study, price pairs could be UD compatible, when the ten and the unit of one price were larger than those of the other price (e.g., 49 euros - 36 cents, where 4 > 3 and 9 > 6) or UD incompatible when the ten of one price was larger, but the unit smaller than those of the other price (46 euros - 39 cents, where 4 > 3 but 6 < 9).

In addition, the NMC compatibility and the UD compatibility were evaluated in three price formats: Arabic numbers, written number words and auditory number words. These three formats were used, on the one hand, to confirm the pattern of UD compatibility effects observed in previous studies across notations (e.g., Macizo & Herrera, 2008): UD compatibility effect with Arabic numbers and lack of compatibility effect (or reverse compatibility effect) with numbers in verbal format. On the other hand, we wanted to examine the NMC compatibility effect in the verbal format because, to our knowledge, it has been never considered in previous research. The study of prices in verbal format is relevant. Although the processing of written number words is rather unusual (e.g., reading numbers written with words), to hear and compare price pairs is a frequent and daily activity in people's lives. Regarding the NMC compatibility effect through price formats, our hypothesis was as follows: If the linguistic structure of the Spanish language favors the processing of the first symbol (the number) of a price, the NMC compatibility effect would be greater in verbal format compared to the Arabic format because it would stress the processing of the irrelevant dimension of the price (the magnitude of the numbers) in the comparison task (price comparison can be done attending only to the second symbol, that is, the monetary category of the prices).

2. Materials and methods

2.1. Participants

Students from the University of Granada served as participants. Three groups of participants were established: Arabic digit group (N = 29, M age = 22.8, 8 men); Written number word group (N = 28, M age = 24.2, 7 men) and Auditory number word group (N = 27, M age = 24, 6 men). Participants were randomly assigned to one of the three groups. All participants used the Euro currency on a daily basis and had normal or corrected-to-normal visual acuity. An informed consent form was signed by the participants before performing the experiment and their participation was rewarded with academic credits. The sample size was determined using G*Power, version 3.1.9.4 (Faul et al., 2007). It was calculated that for a 3 × 2 × 2 multivariate analysis of variance (MANOVA) to achieve 80% statistical power with α =0.05 and an effect size of 0.25, the total sample size needed was N = 30.

2.2. Task

The present experiment was designed and controlled by the experimental software *E*-Prime 2.0 (Schneider et al., 2002). A price comparison task was used where, in each trial, a pair of two-digits prices in the euro currency were presented sequentially and participants had to decide which one has the higher monetary value. Participants used the keyboard to give their answers by pressing "A" or "L" keys. The assignment of the first/second price to the A/L keys was counterbalanced across participants. Depending on the group, prices were presented in three different formats: Arabic digits, written number words or auditory number words. The experimental task used in the current study is freely available at https://osf.io/h6fqm/?view_only=4d197ebbc27e4299aeaf83e2aa990123

The simultaneous presentation of price pairs would have been preferable to the sequential presentation since the magnitude of the compatibility effects is greater with the simultaneous vs. sequential procedure in number comparison tasks (Moeller et al., 2013) and price comparison tasks (Macizo & Ojedo, 2018). However, in the current study, we selected the sequential presentation due to the introduction of auditory number words in one experimental condition whose number and monetary category must be processed sequentially over time. Nevertheless, with the sequential procedure, compatibility effects are also observed with two-digit numbers (Macizo & Herrera, 2008) and prices (Macizo & Ojedo, 2018; Ojedo & Macizo, 2020).

2.3. Stimuli and design

All prices used in the task were formed by a two-digit number (between 21 and 98) and a monetary category (euro or cent). The experimental trials were always comparisons between monetary categories. Pair of prices formed by the same digits were not included in the task (e.g., 39 euros - 39 cents, or 93 euros - 39 cents were not used). The price comparisons used in the study were the same in the three groups of participants; the only difference between the groups was the format in which the prices were presented.

Three independent variables were considered in the study. The format of prices was manipulated across participants (i.e., the price format was a between-participant factor) (Arabic digits, written number words, and auditory number words), while the NMC compatibility and the UD compatibility were manipulated within-participants. Thus, a mixed 3 × 2 × 2 design was employed in the study. Prices were number-monetary category (NMC) compatible (49 euros - 36 cents) when the numbers and monetary category of one price were larger than those of the other (49 > 36, euros > cents); and they were NMC incompatible (49 cents - 36 euros) when the number of one price was larger but the monetary category smaller than those of the other (49 > 36, cents < euros). In addition, prices were UD compatible when the decade and unit of one price were larger than those of the other (49 euros, 36 cents, 4 > 3, 9 > 6); while they were UD incompatible when the decade of one price was larger but the unit smaller than those of the other (46 euros -

Table 1
Examples of compatibility conditions in the study.

	Unit-decade compatible	Unit-decade incompatible
Number-Monetary Category Compatible	**68 euros** > 53 cents	**63 euros** > **48** cents
Number-Monetary Category Incompatible	53 **euros** > **68** cents	**48 euros** > **63** cents

Note. The stimuli were presented in the same font type. In the table, the tens, units and the largest monetary category in each of the price pairs are highlighted.

39 cents, 4 > 3, 6 < 9) (see Table 1).

The experimental stimuli were composed of two-digit number pairs. These stimuli were previously used in number comparison tasks conduced in our laboratory (Macizo & Herrera, 2008, 2010). One-hundred twenty number pairs were UD compatible and 120 were UD incompatible. The compatible and incompatible number pairs were equated in their absolute distance, unit distance and problem size (mean value of the two numbers) (see Table 2). A series of *t*-tests revealed that all these measures were similar in compatible and incompatible number pairs (all *ps* > 0.05). The only difference between them was observed in the decade distance which is due to the necessity of equating the overall distance. Decade numbers (i.e., numbers that refer to decades; e.g., 30, 40, 50, etc.) and tie numbers (i.e., two-digit numbers in which the decade and the unit refer to the same digit; e.g., 33, 44, 55, etc.) were not included. The 240 experimental price pairs (120 UD compatible and 120 UD incompatible) were presented in both the NMC compatible condition and the NMC incompatible condition, so that numerical variables were controlled between NMC compatible and incompatible conditions (e.g., decade distance, unit distance, etc.). Overall, each participant received 480 experimental stimuli presented randomly throughout the experiment: 120 UD compatible – NMC compatible prices, 120 UD compatible – NMC incompatible prices, 120 UD incompatible – NMC compatible prices, 120 UD incompatible – NMC incompatible prices.

In addition to the 480 experimental price pairs (between monetary category comparisons), a set of 240 filler trials were used. These trials were introduced with the aim of ensuring that the participants did not carry out the comparison task on the basis of the monetary category or the decade of prices only. Thus, 120 filler trials with the same monetary category were included. Sixty of these trials were prices in euro (30 UD compatible and 30 UD incompatible trials) and another 60 trials were prices in cents (30 UD compatible and 30 UD incompatible trials). Furthermore, 120 additional filler trials comprised within-decade numbers: 40 trials with euro-cent price pairs, 40 trials with euro prices, and 40 trials with cent prices. Thus, each participant received 720 trials (480 experimental comparisons and 240 filler comparisons). The price pairs were presented randomly in 6 blocks of 120 trials each so that participants could rest between blocks. Stimuli used in the study are fully and freely accessible at https://osf.io/h6fqm/?view_only=4d197ebbc27e4299aeaf83e2aa990123

Table 2
Characteristics of two-digit numbers that composed the prices used in the study.

	Compatible numbers	Incompatible numbers
Abs diff.	36.83 (18.40)	34.93 (18.11)
Log. diff.	1.50 (0.25)	1.47 (0.27)
Abs. diff. Log.	0.31 (0.16)	0.28 (0.15)
Decade diff.	3.30 (1.86)	3.88 (1.83)*
Decade diff. Log.	0.43 (0.29)	0.53 (0.24)*
Unit diff.	3.83 (2.14)	3.83 (2.14)
Unit diff. Log.	0.50 (0.29)	0.50 (0.29)
Problem size	57.27 (15.04)	59.65 (13.10)
Problem size log.	1.74 (0.12)	1.76 (0.10)
Word length	24.48 (1.75)	24.46 (1.78)
Syllable number	10.28 (1.15)	10.46 (1.05)
Decade length	14.36 (1.19)	14.28 (1.04)
Unit length	8.47 (1.35)	8.53 (1.26)
Duration	2008.14 (95.14)	2007.26 (85.28)

Note. Abs. = Absolute, Diff. = Difference of the numbers, Log. = logarithmic values. Word length and syllable number correspond to the number of letters and syllables of each two-digit numbers in Spanish. Decade and unit lengths refer to the number of letters of decades and units of each two-digit numbers in Spanish, respectively. Standard deviations are in brackets. Duration refers to the length (in milliseconds) of the numbers in auditory format (sum of the two numbers presented in each pair of prices). *$p < .05$ (compatible numbers vs. incompatible numbers).

2.4. Procedure

Participants were tested individually, seated 60–70 cm approximately from the computer screen (Captativa E1903D, LCD, 1280 × 1024, 60 Hz, 19″). Each stimulus was presented in Arial 30-point font, in black font on a white background. Since auditory stimuli (auditory number words) are necessarily presented in a sequential manner, prices with Arabic numbers and written number words were also presented sequentially. In each trial, a fixation point (a row of asterisks) was presented in the middle of the screen for 500 ms. Then, the first price appeared during 1000 ms, followed by a mask (row of Xs) which was presented for 50 ms. Then, after a delay of 250 ms, the second price was presented until the response of the participant (see Fig. 1).

The reason for using a backward mask was to avoid the low-level perceptual influences of the rapid change at digits and monetary category positions as a result of the short interval of time between the two stimuli to be compared. In addition, to control for this factor, the position of the two prices at the centre of the screen was not exactly the same. In each trial, the position of the second price was moved randomly by one character position to the left or to the right (see Macizo & Ojedo, 2018; Moeller et al., 2013, for the same procedure).

3. Results

Data are fully and freely accessible at https://osf.io/h6fqm/?view_only=4d197ebbc27e4299aeaf83e2aa990123. Trials in which participants committed an error were excluded from the latency analysis and submitted to the error rate analysis (Arabic digits: 4.69%; written number words 4.28%; auditory numbers: 4.69%). Afterwards, the reaction times (RTs) associated with correct responses were trimmed following the procedure described by (Tabachnick & Fidell, 2007) in order to eliminate univariate outliers. Raw scores were converted to standard scores (*z*-scores). Data points which, after standardization were 3 *SD* outside the normal distribution, were considered outliers. After removing outliers from the distribution, *z*-scores were calculated again. The filter was applied in recursive cycles until no observations were outside 3 *SD*. The percentage of outliers was 7.78% for price pairs presented with Arabic digits, 6.62% for price pairs presented with written number words and 3.58% for price pairs presented in the auditory format.

RTs and error rates were submitted to analysis of variance (ANOVA) with NMC compatibility (two levels: NMC compatible trials, NMC incompatible trials) and UD compatibility (two levels: UD compatible trials, UD incompatible trials) as within-participant factors, and format of the price pairs (three levels: Arabic digits, written number words, auditory numbers) as a between-participant factor.

In the latency analysis, the format effect was significant, $F(1, 81) = 154.84$, $p < .001$, $\eta^2 = 0.79$. The difference between the processing of prices in Arabic format ($M = 683$ ms, $SE = 42$) and prices written with number words ($M = 780$ ms, $SE = 43$) was marginal, $t(55) = -1.80$, $p = .07$. Furthermore, price pairs with written number words were responded to faster than price pairs in the auditory format ($M = 1664$ ms, $SE = 44$), $t(53) = -13.19$, $p < .001$. The NMC compatibility effect was significant, $F(1, 81) = 43.21$, $p < .001$. $\eta^2 = 0.35$. Participants were faster in NMC compatible trials ($M = 1005$ ms, $SE = 28$) than in NMC incompatible trials ($M = 1080$ ms, $SE = 22$). The UD compatibility effect was not significant, $F(1, 81) = 0.15$, $p = .69$, $\eta^2 = 0.01$. There were no differences between the UD compatible condition ($M = 1043$ ms, $SE = 25$) and the UD incompatible condition ($M = 1042$ ms, $SE = 25$). The interaction between Format x NMC Compatibility factors was significant, $F(2, 81) = 20.93$, $p < .001$. $\eta^2 = 0.34$. No other interactions were significant (all *ps* > 0.05). The NMC compatibility effect was significant when prices were processed in Arabic format, $t(29) = 6.11$, $p < .001$, and in oral format, $t(27) = 5.24$, $p < .001$. The NMC compatibility effect was marginal when prices were presented with number words, $t(28) = 1.87$, $p = .07$. Thus, the interaction was due to differences in the magnitude of

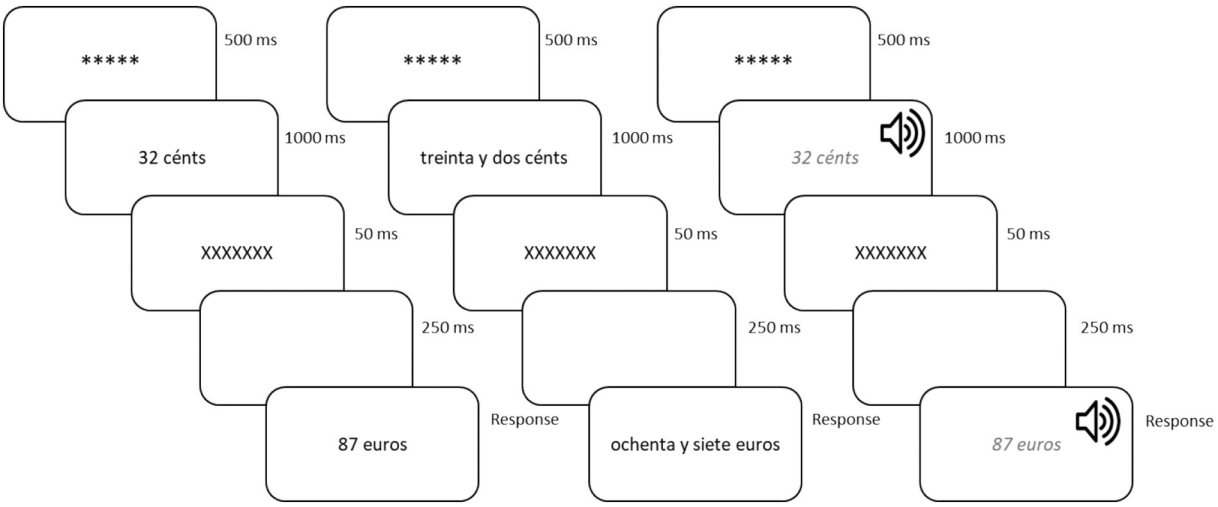


Fig. 1. Procedure used in the study.

the NMC compatibility effect across the format of the prices (see Table 3). In fact, *t*-test analyses revealed that the magnitude of the NMC compatibility effect (NMC incompatible minus NMC compatible) was greater with prices in the auditory format (181 ms) compared to both, prices with Arabic numbers (32 ms), $t(54) = 4.41$, $p < .001$, and prices with written number words (13 ms), $t(53) = 4.85$, $p < .001$. In addition, the magnitude of the NMC compatibility effect was greater with prices in the written number word format than with prices in the Arabic digit format, $t(55) = 2.20$, $p = .03$.

Regarding the error rate analysis, the format effect was not significant, $F(2, 81) = 0.09$, $p = .92$, $\eta^2 = 0.01$. Mean percentage of errors was $M = 4.69\%$ ($SE = 0.80$) in the Arabic digit format, $M = 4.28\%$ ($SE = 0.82$) in the written number word format, and $M = 4.70\%$ ($SE = 0.83$) in the auditory format. The NMC compatibility was significant, $F(1, 81) = 49.39$, $p < .001$. $\eta^2 = 0.38$, participants committed fewer errors in NMC compatible trials ($M = 3.52\%$, $SE = 0.45$) than in NMC incompatible trials ($M = 5.60\%$, $SE = 0.53$). The UD compatibility effect was not significant $F(1, 81) = 0.04$, $p = .83$, $\eta^2 = 0.01$. The interaction between Format x NMC Compatibility factors was significant, $F(2, 81) = 3.14$, $p = .05$. $\eta^2 = 0.07$. No other interactions were significant. The NMC compatibility effect was significant when participants processed prices in Arabic format, $t(29) = 5.04$, $p < .001$, written format, $t(28) = 3.25$, $p = .003$, and oral format, $t(27) = 3.99$, $p < .001$. Thus, as in the latency analyses, the interaction was due to differences in the magnitude of the NMC compatibility effect across price formats.

The three-way interaction was not significant in either the latency analyses or the error rate analyses. Therefore, it is not statistically justified to decompose this interaction. However, in order to have a complete profile of the pattern of results, further analyses were conducted. For each numerical format, three separate analysis of variance (ANOVA) were conducted with NMC compatibility (two levels: NMC compatible trials, NMC incompatible trials) and UD compatibility (two levels: UD compatible trials, UD incompatible trials) as within-participant factors. These analyses are described in a separate document available at https://osf.io/h6fqm/?view_only=4d197ebbc27e4299aeaf83e2aa990123

The results found in these analyses confirmed the pattern of data reported here.

Table 3
Number-monetary compatibility and unit-decade compatibility effects across formats.

	Unit-decade (UD) compatibility			
	UD compatible		UD incompatible	
Number-monetary category (NMC) compatibility	RT	E%	RT	E%
Price pairs with Arabic digits				
NMC compatible	668	2.84	666	3.42
	(33)	(0.59)	(35)	(0.66)
NMC incompatible	700	6.35	699	6.15
	(35)	(0.85)	(35)	(0.70)
NMC compatibility effect: 32 ms*				
UD compatibility effect: −2 ms				
Price pairs with written number words				
NMC compatible	773	3.93	774	3.04
	(41)	(0.75)	(42)	(0.67)
NMC incompatible	781	5.06	792	5.09
	(42)	(0.87)	(44)	(0.98)
NMC compatibility effect: 13 ms~				
UD compatibility effect: 6 ms				
Price pairs with auditory numbers				
NMC compatible	1582	3.80	1565	4.07
	(66)	(1.05)	(70)	(1.04)
NMC incompatible	1755	5.25	1755	5.68
	(40)	(1.09)	(38)	(1.22)
NMC compatibility effect: 181 ms*				
UD compatibility effect: −8 ms				

Note. Reaction times (RT) (in milliseconds), error percentage (E%), and standard error (in parentheses) according to the Number-Monetary Category (NMC) compatibility and the Unit-Decade (UD) compatibility, obtained with price pairs presented with Arabic digits, written number words and auditory numbers. NMC Compatibility effect = NMC Incompatible minus NMC Compatible (RT). UD Compatibility effect = UD Incompatible minus UD Compatible (RT). *$p < .001$, ~$p = .07$.

4. Discussion

To our knowledge, there are no previous studies that have evaluated the possible differences in the way people process prices through different formats (prices with Arabic numbers, prices with written number words, and prices in oral format). This comparison is particularly relevant: the vast majority of studies on price processing have been conducted in Arabic format (Cao et al., 2012; Macizo & Ojedo, 2018); however, price in verbal format (e.g., oral price processing) is a common activity in everyday life (e.g., listen to the cashier of a supermarket for the amount of money you have to pay, listening to financial news, etc.). The objective of this study was twofold, on the one hand, to evaluate the possible differences in price processing depending on the format in which prices were coded and, on the other hand, to investigate the possible componential analysis of two-digit numbers embedded within prices. To investigate these two goals, we considered the NMC compatibility effect and the UD compatibility effect in price comparison

tasks with Arabic digits and verbal numbers (written number words and oral numbers).

The results of the current study revealed NMC compatibility effects across numerical formats. The presence of this effect with Arabic numbers has been confirmed in previous studies with one-digit price pairs (Macizo & Ojedo, 2018; Ojedo & Macizo, 2020), and suggests that prices are processed in a componential manner with separate processing of the two constituent symbols (the number and the monetary category). The present study shows for the first time NMC compatibility effect with two-digit price pairs. Thus, although early studies with the comparison task suggested that prices were processed holistically (Cao et al., 2015, 2012), the data from this study and previous works confirm the componential perspective. In addition, the NMC compatibility effect was found when prices were presented with both Arabic numbers and verbal numbers (written and auditory number words). The occurrence of NMC compatibility effects across different notations indicates that prices are analyzed componentially irrespective of their initial encoding (visual, auditory) and the format in which the magnitudes are represented (Arabic numbers, orthographic and auditory number words). This pattern of results is in favor of a general framework of multi-symbol magnitude processing according to which all quantities are processed componentially (multi-symbol numbers, units of measurement, etc.) (Huber et al., 2016).

However, although NMC compatibility effects were consistently found through price notations, the magnitude of the effect varied depending on the format. In particular, the magnitude of the NMC compatibility effect with Arabic numbers (32 ms difference between NMC incompatible trials vs. NMC compatible trials) was close to that obtained in previous studies (approximately 43 ms in Macizo & Ojedo, 2018). In contrast, the magnitude of the NMC compatibility effect was greater in the auditory format than in the rest of notations (181 ms). The increased NMC compatibility effect in the verbal format vs. Arabic format was predicted in the introduction section. The processing of the first symbol of a multi-digit magnitude is emphasized in languages such as Spanish (i.e., the ten, in two-digit numbers). In the context of the processing of prices, this would involve a greater processing of the number vs. the monetary category in the verbal format, which would increase the interference because the number of a price is irrelevant for comparing between monetary category price pairs. Thus, in NMC incompatible comparisons such as 36 euros - 49 cents, the euros > cents comparison would be sufficient to answer and the analysis of the numbers would interfere with the processing by leading to a different answer (36 < 49). Nevertheless, we did not have specific hypotheses about possible differences in price processing across the two verbal formats (written and oral presentation of prices). However, in our study, the magnitude of the NMC compatibility effect was greater with auditory words (181 ms) than with number words (13 ms).

As noted, the difference between the two verbal formats (prices with written number words and prices with oral numbers) was not predicted before conducting and analyzing the data of the current study. However, this difference in the magnitude of the NMC compatibility effect between verbal formats resembles other format-dependent effects observed in other areas of cognition concerning semantic processing. For example, in classical semantic priming studies, the facilitation effect due to the semantic relationship between pairs of words (faster processing of semantically related vs. unrelated word pairs, e.g., dog - cat vs. car - pen, respectively) is greater with auditory words (109 ms) than with written words (33 ms) (Holcomb & Neville, 1990). These differences between formats are interpreted as evidence of the greater and faster semantic processing of the stimuli in the oral vs. written format. In the case of price processing, this would imply an increased processing of the price magnitude (i.e., the semantic content of prices) in the oral vs. written format which would enhance the NMC compatibility effect with auditory numbers.

Concerning the second objective of our study, the results did not reveal UD compatibility effects in any of the price formats we examined (prices with Arabic numbers, written number words and auditory number words). The absence of UD compatibility effect in the verbal format confirms the results obtained when participants process two-digit number pairs presented in isolation (Macizo & Herrera, 2008) which seem to indicate the influence of languages such as Spanish in which more relevance is given to the processing of the ten than the unit of two-digit numbers. However, the UD compatibility effect with Arabic numbers appears to be language-independent and it is found in all the languages in which it has been examined such as English (Nuerk et al., 2005), Spanish (Macizo & Herrera, 2008, 2010, 2011a,b; Macizo et al., 2011), German (Macizo et al., 2011; Moeller et al., 2011, 2013; Nuerk et al., 2001), and Italian (Macizo et al., 2010). This pattern of results could be interpreted in terms of a hybrid view in which the processing of the magnitude is both holistic and componential (e.g., Nuerk & Willmes, 2005). As noted in the introduction section, within the hybrid model of magnitude processing, it is assumed that in number comparison tasks, an analysis of both the holistic magnitude and the magnitude of each of the constituent symbols is produced (Moeller et al., 2011). From this perspective, the weight of holistic vs. componential processing would depend on different factors. For example, holistic vs. componential processing would be more relevant in case of an approximate vs. exact comparison task. In addition, it would also depend on the type of symbols with which the magnitude is represented. For instance, while componential analysis seems to predominate in multidigit number processing, in the case of fractions, both componential and holistic processing would be relevant (e.g., models indicating a componential processing followed by the accessing to the overall magnitude of the fraction) (Meert et al., 2009, 2010). Regarding the processing of prices composed of a two-digit number and a monetary category, this hybrid perspective would imply a componential analysis of the number and the monetary category but a greater weight of holistic processing for the analysis of the tens and the units that comprise the two-digit number.

This possible hybrid (compositional and holistic) processing of prices could stem from the visual configuration of prices in the comparison task. Pletzer et al. (2016) observed a reduced UD compatibility effect when two-digit number pairs were more spaced (distant spacing condition) compared to a condition where the numbers were closer together. The authors suggested that the distant spacing condition might favor the grouping and holistic processing of the ten and the unit of the numbers in the comparison task. This interpretation would be in line with the results of our study. Thus, when considering a pair of prices (e.g., 68 euros - 53 cents), the number and the monetary category would be more spaced out than the ten and the unit of the numbers. This spatial arrangement would favor the holistic processing of the two-digit numbers which would prevent the UD compatibility effect in our study.

5. Conclusions

To our knowledge, this is the first study to evaluate whether the processing of prices composed of two-digit numbers is holistic or componential and whether the coding of the price format influences price comparison. The results of this study appear to favor a hybrid model with a greater weight of componential processing for the analysis of the number and the monetary category and a greater relevance of the holistic processing for the analyses of the constituents of two-digit numbers (tens and units). In addition, the format of the prices does not seem to modulate the type of analysis (componential vs. holistic) but it emphasizes the processing of the number vs. the monetary category when people listen to prices compared to the reading of prices written with Arabic numbers or number words.

CRediT authorship contribution statement

Fernando Ojedo: Conceptualization, Methodology, Software, Formal analysis, Data Curation, Investigation, Writing - Original Draft. **Pedro Macizo:** Conceptualization, Methodology, Resources, Writing -

Original Draft, Supervision, Project administration, Funding acquisition.

Data availability

The datasets generated during the current study are available in the Open Science Framework (OSF) repository, https://osf.io/h6fqm/?view_only=4d197ebbc27e4299aeaf83e2aa990123

Acknowledgements

Preparation of this manuscript was supported by a grant awarded to Pedro Macizo by the Spanish Ministry of Science and Innovation (PID2019-111359GB-I00 / SRA State Research Agency /10.13039/501100011033). The study was undertaken in accordance with the 1964 Helsinki declaration. The Ethics Committee at the University of Granada approved the experimental procedures (Number issued by the Ethical Committee: 957/CEIH/2019) and each participant provided written informed consent before taking part in the experiment. In order to comply with APA Ethics Code Standard 8.14a (sharing research data for verification), the stimuli, experimental procedure, data and analyses reported in this manuscript have been stored in a freely accessible repository (reference links have been indicated in the manuscript). The authors declare no conflict of interest.

References

Cao, B., Gao, H., & Li, F. (2015). Hybrid model of price pair comparisons: Evidence from an event-related potential study. *NeuroReport, 26*(14), 838–841. https://doi.org/10.1097/WNR.0000000000000433

Cao, B., Li, F., Zhang, L., Wang, Y., & Li, H. (2012). The holistic processing of price comparison: Behavioral and electrophysiological evidences. *Biological Psychology, 89*(1), 63–70. https://doi.org/10.1016/j.biopsycho.2011.09.005

Dehaene, S., & Marques, J. F. (2002). Cognitive euroscience: Scalar variability in price estimation and the cognitive consequences of switching to the euro. *Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology, 55*(3), 705–731. https://doi.org/10.1080/02724980244000044

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G* power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. https://doi.org/10.3758/BF03193146

Goldman, R., Ganor-Stern, D., & Tzelgov, J. (2012). "On the money" - monetary and numerical judgments of currency. *Acta Psychologica, 141*(2), 222–230. https://doi.org/10.1016/j.actpsy.2012.07.005

Holcomb, P. J., & Neville, H. J. (1990). Auditory and visual semantic priming in lexical decision: A comparison using event-related brain potentials. *Language & Cognitive Processes, 5*(4), 281–312. https://doi.org/10.1080/01690969008407065

Huber, S., Bahnmueller, J., Klein, E., & Moeller, K. (2015). Testing a model of componential processing of multi-symbol numbers—Evidence from measurement units. *Psychonomic Bulletin and Review, 22*(5), 1417–1423. https://doi.org/10.3758/s13423-015-0805-8

Huber, S., Cornelsen, S., Moeller, K., & Nuerk, H. C. (2015). Toward a model framework of generalized parallel componential processing of multi-symbol numbers. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 41*(3), 732–745. https://doi.org/10.1037/xlm0000043

Huber, S., Moeller, K., Nuerk, H.-C., & Willmes, K. (2013). A computational modeling approach on three-digit number processing. *Topics in Cognitive Science, 5*(2), 317–334. https://doi.org/10.1111/tops.12016

Huber, S., Nuerk, H.-C., Willmes, K., & Moeller, K. (2016). A general model framework for multisymbol number comparison. *Psychological Review, 123*(6), 667. https://doi.org/10.1037/rev0000040

Macizo, P. (2017). Conflict resolution in two-digit number processing: Evidence of an inhibitory mechanism. *Psychological Research, 81*(1), 219–230. https://doi.org/10.1007/s00426-015-0716-3

Macizo, P., & Herrera, A. (2008). El efecto del código numérico en la tarea de comparación de números de dos cifras. [the effect of number codes in the comparison task of two-digit numbers.]. *Psicológica, 29*(1), 1–34.

Macizo, P., & Herrera, A. (2010). Two-digit number comparison: Decade-unit and unit-decade produce the same compatibility effect with number words. *Canadian Journal of Experimental Psychology, 64*(1), 17–24. https://doi.org/10.1037/a0015803

Macizo, P., & Herrera, A. (2011a). Cognitive control in number processing: Evidence from the unit-decade compatibility effect. *Acta Psychologica, 136*(1), 112–118. https://doi.org/10.1016/j.actpsy.2010.10.008

Macizo, P., & Herrera, A. (2011b). Working memory and two-digit number processing. *Memory, 19*(8), 941–955. https://doi.org/10.1080/09658211.2011.614621

Macizo, P., & Herrera, A. (2013). Do people access meaning when they name banknotes? *Cognitive Processing, 14*(1), 43–49. https://doi.org/10.1007/s10339-012-0531-3

Macizo, P., Herrera, A., Paolieri, D., & Román, P. (2010). Is there cross-language modulation when bilinguals process number words? *Applied PsychoLinguistics, 31*(4), 651–669. https://doi.org/10.1017/S0142716410000184

Macizo, P., Herrera, A., Román, P., & Martín, M. C. (2011). The processing of two-digit numbers in bilinguals. *British Journal of Psychology, 102*(3), 464–477. https://doi.org/10.1111/j.2044-8295.2010.02005.x

Macizo, P., & Morales, L. (2015). Cognitive processing of currency: Euros and dollars. *British Journal of Psychology, 106*(4), 583–596. https://doi.org/10.1111/bjop.12114

Macizo, P., & Ojedo, F. (2018). The processing of price comparison is not holistic but componential. *Psychological Research, 82*(6), 1144–1157. https://doi.org/10.1007/s00426-017-0884-4

Meert, G., Grégoire, J., & Noël, M. P. (2009). Rational numbers: Componential versus holistic representation of fractions in a magnitude comparison task. *Quarterly Journal of Experimental Psychology, 62*(8), 1598–1616. https://doi.org/10.1080/17470210802511162

Meert, G., Grégoire, J., & Noël, M. P. (2010). Comparing the magnitude of two fractions with common components: Which representations are used by 10- and 12-year-olds? *Journal of Experimental Child Psychology, 107*(3), 244–259. https://doi.org/10.1016/j.jecp.2010.04.008

Moeller, K., Huber, S., Nuerk, H. C., & Willmes, K. (2011). Two-digit number processing: Holistic, decomposed or hybrid? A computational modelling approach. *Psychological Research, 75*(4), 290–306. https://doi.org/10.1007/s00426-010-0307-2

Moeller, K., Klein, E., Nuerk, H. C., & Willmes, K. (2013). Magnitude representation in sequential comparison of two-digit numbers is not holistic either. *Cognitive Processing, 14*(1), 51–62. https://doi.org/10.1007/s10339-012-0535-z

Moeller, K., Nuerk, H. C., & Willmes, K. (2009). Internal number magnitude representation is not holistic, either. *European Journal of Cognitive Psychology, 21*(5), 672–685. https://doi.org/10.1080/09541440802311899

Moyer, R., S., & Landauer, T., K. (1967). Time required for judgements of numerical inequality. *Nature, 215*, 1519–1520. https://doi.org/10.1038/2151519a0

Nuerk, H., & Willmes, K. (2005). On the magnitude representations of two-digit numbers. *Psychology Science, 47*(1), 52–72.

Nuerk, H. C., Moeller, K., Klein, E., Willmes, K., & Fischer, M. H. (2011). Extending the mental number line. *Zeitschrift für Psychologie, 219*(1), 3–22. https://doi.org/10.1027/2151-2604/a000041

Nuerk, H. C., Weger, U., & Willmes, K. (2001). Decade breaks in the mental number line? Putting the tens and units back in different bins. *Cognition, 82*(1), B25–B33. https://doi.org/10.1016/S0010-0277(01)00142-1

Nuerk, H. C., Weger, U., & Willmes, K. (2005). Language effects in magnitude comparison: Small, but not irrelevant. *Brain and Language, 92*(3), 262–277. https://doi.org/10.1016/j.bandl.2004.06.107

Ojedo, F., & Macizo, P. (2020). How do we process prices? Electrophysiological evidence of componential analysis. *British Journal of Psychology, 111*(3), 473–491. https://doi.org/10.1111/bjop.12425

Pletzer, B., Harris, T., & Scheuringer, A. (2019). Sex differences in number magnitude processing strategies are mediated by spatial navigation strategies: Evidence from the unit-decade compatibility effect. *Frontiers in Psychology, 10*, 229. https://doi.org/10.3389/fpsyg.2019.00229

Pletzer, B., Scheuringer, A., & Harris, T. (2016). Spacing and presentation modes affect the unit-decade compatibility effect during number comparison. *Experimental Psychology, 63*, 189–195. https://doi.org/10.1027/1618-3169/a000326

Pletzer, B., Scheuringer, A., Harris, T., & Scherndl, T. (2020). *The missing link: Global-local processing relates to number-magnitude processing in women*. Journal of Experimental Psychology: *General*. Advance online publication. https://doi.org/10.1037/xge0000951

Ruiz, A., Togato, G., García-Gámez, A. B., & Macizo, P. (2017). Individual differences in banknote processing: The role of altruism. *Journal of Cognitive Psychology, 29*(2), 169–183. https://doi.org/10.1080/20445911.2016.1237954

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-prime: User's guide* (Psychology Software Incorporated).

Schwarz, W., & Heinze, H. J. (1998). On the interaction of numerical and size information in digit comparison: A behavioral and event-related potential study. *Neuropsychologia, 36*(11), 1167–1179. https://doi.org/10.1016/S0028-3932(98)00001-3

Szucs, D., & Soltész, F. (2007). Event-related potentials dissociate facilitation and interference effects in the numerical Stroop paradigm. *Neuropsychologia, 45*(14), 3190–3202. https://doi.org/10.1016/j.neuropsychologia.2007.06.013

Tabachnick, B. G., & Fidell, L. S. (2007). *Using multivariate statistics, 5th ed. using multivariate statistics* (5th ed.). Boston, MA: Allyn & Bacon/Pearson Education.

Thomas, M., & Morwitz, V. (2005). Penny wise and pound foolish: The left-digit effect in price cognition. *Journal of Consumer Research, 32*(1), 54–64. https://doi.org/10.1086/429600